International Journal of Engineering Technology and Science (IJETS)
Volume 1, Issue 1 : Page No. 1-10
www.ijets.webs.com

THD Reduction in Renewable Energy System with Multilevel Inverter

K.Venkata Kishore[1], T.Vijay Muni[2], N.Sesha Reddy[3]

Assistant Professor[1] , Associate Professor[2], Assistant Professor[3]

[1,2,3] Department of EEE, NRI Institute of Technology, Vijayawada, A.P, India

Abstract: This paper presents the control of a multilevel inverter supplied by a Photovoltaic (PV) panel, wind and a batteries bank. It is well known that the power quality of multilevel inverter signals depends on their number of levels. However, the question that arises is whether there is a limit beyond which it is not necessary to increase the number of level. This question is addressed in this paper by studying seven-level and nine - level diode clamped converters. The harmonics content of the output signals are analyzed. Comparison between the seven level and nine level diode clamped converter is shown. A simplified Pulse Width Modulation (SPWM) method for a multilevel inverter is developed. The controller equations are such that the SPWM pulses are generated automatically for any number of levels. The effectiveness of the propose method is evaluated in simulation. Matlab®/Simulink is used to implement the control algorithm and simulate the system.

Keywords: Multilevel inverter, Multilevel SPWM, THD

I. INTRODUCTION

Nowadays, the industry requires power equipment increasingly high, in the megawatt range. The rapid evolution of semiconductor devices manufacturing technologies and the designer's orientation has enabled the development of new structures of converters (inverters) with a great performance compared to conventional structures. So, these new technologies of semiconductor are more suited to high power applications and they enable the design of multilevel inverters. The constraints due to commutation phenomena are also reduced and each component supports a much smaller fraction of the DC-bus voltage when the number of levels is higher. For this reason, the switches support more high reverse voltages in high-power applications and the converter output signals are with good spectral qualities.

Thus, the using of this type of inverter, associated with a judicious control of power components, allows deleting some harmonics [1]. Among the control algorithms proposed in the literature in this field [2-3-4], the SPWM, appears most promising. It offers great flexibility in optimizing the design and it is well suited for digital implementation. It also helps to maximize the available power. The main advantage of multilevel inverters is that the output voltage can be generated with a low harmonics. Thus it is admitted that the harmonics decrease proportionately to the inverter level. For these reasons, the multilevel inverters are preferred for high power applications. However, there is no shortage of disadvantages. Their control is much more complex and the techniques are still not widely used in industry [7-8].

In this paper, modelling and simulation of a multilevel inverter using Neutral-Point-Clamped (NPC) inverters have been performed with motor load using Simulink/ MATLAB program.

In the first section multilevel inverter control strategies are presented before to detail a study of *seven-level* inverter in the second section. Total Harmonic Distortion (THD) is discussed in the third section. The aim is to highlight the limit at which the multilevel inverters are no longer effective in reducing output voltage harmonics.

II. SYSTEM DESCRIPTION

The system consists of a PV-FC-WIND hybrid source. The photovoltaic [3], [4], wind mill and the PEMFC [5],[6] are modeled as nonlinear voltage sources. These sources are connected to dc–dc converters which are coupled at the dc side of a dc/ac diode clamped multilevel inverter.

Photovoltaic (PV) systems are stand-alone power generators that have good environmental footprints. The modelling and the Maximum Power Point Tracking (MPPT) control strategy for a PV system are developed in [9]. In the latter, the control strategy that is presented is based only on the measurement of the PV current to track the maximum power. A batteries bank and the energy from the wind mill is added to the DC-bus to ensure the energetic autonomy of the system.

A Proportional-Integral (PI) controller is used to regulate the DC-bus voltage at a constant value. As a consequence the batteries and the wind energy compensate for the difference between the power supplied by the PV system and the power needed by the load. The batteries are charged when the PV power exceeds the load demand [10].

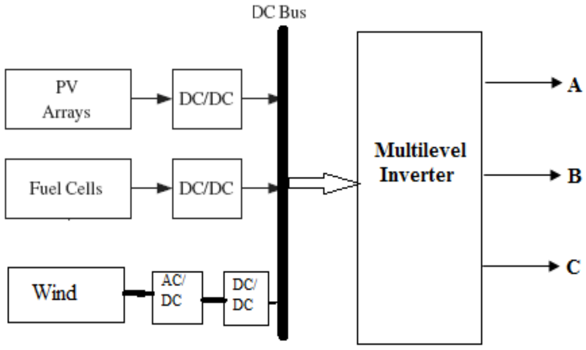


Figure – 1: Block diagram of the proposed circuit

III. RENEWABLE ENERGY SOURCES (RES)

3.1 PV Array Model

PV modules still have relatively low conversion efficiency; therefore, controlling maximum power point tracking (MPPT) for the solar array is essential in a PV system. The amount of power generated by a PV depends on the operating voltage of the array. A PV's maximum power point (MPP) varies with solar insulation and temperature. It's V-I and V-P characteristic curves specify a unique operating point at which maximum possible power is delivered. At the MPP, the PV operates at its highest efficiency. Therefore, many methods have been developed to determine MPPT [3],[4].

$$I = I_{\mathrm{ph}} - I_{\mathrm{sat}} \left\{ \exp\left[\frac{q}{AKT}(V + IR_s) \right] - 1 \right\}. \qquad (1)$$

Where V and I represent the output voltage and current of the PV, respectively; R_s and R_{sh} are the series and shunt resistance of the cell; q is the electronic charge; I_{sc} is the light-generated current; I_o is the reverse saturation current; n is a dimensionless factor; k is the Boltzmann constant, and Tk is the temperature in ^{0}K. Equation (1) was used in computer simulations to obtain the output characteristics of a solar cell, as shown in Figure 3. This curve clearly shows that the output characteristics of a solar cell are non-linear and are crucially influenced by solar radiation, temperature and load condition. Each curve has a MPPT, at which the solar array operates most efficiently.

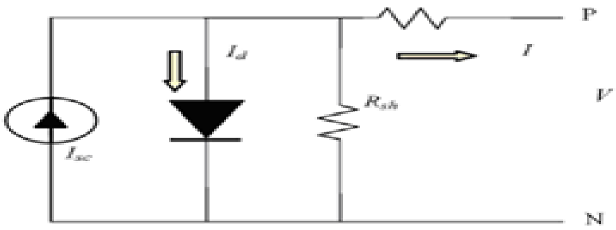


Figure – 2: Equivalent circuit of PV array

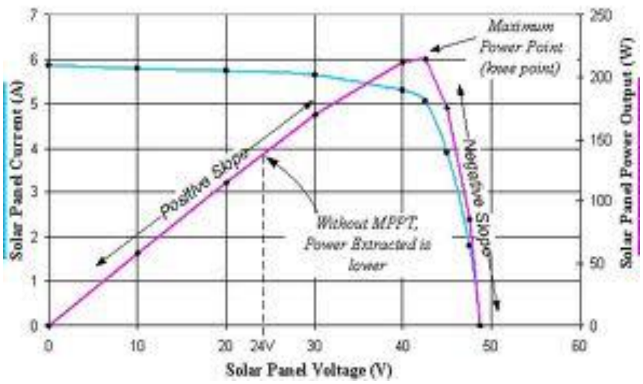


Figure – 3: V-I Characteristic of a solar cell

3.2 PEMFC Model

Among various types of fuel cells, such as, Alkaline (AFC), Phosphoric Acid (PAFC), Molten Carbonate (MCFC), Solid Oxide (SOFC), Proton Exchange Membrane fuel cells (PEMFC) are the most promising. PEM fuel cells are favored for low temperature ~80^0C)- low pressure (~3atm) operation, high power density and good transient capability. A mathematical approach is presented for building a dynamic model for a PEM fuel-cell stack [5]. To simplify the analysis, the following assumptions are made

- One-dimensional treatment.
- Ideal and uniformly distributed gases.
- Constant pressures in the fuel-cell gas flow channels.
- The fuel is humidified H_2 and the oxidant is humidified air. Assume the effective anode water vapor pressure is 50% of the saturated vapor pressure while the effective cathode water pressure is 100%.
- The fuel cell works under 100^0C and the reaction product is in liquid phase.

Thermodynamic properties are evaluated at the average stack temperature, temperature variations across the stack are neglected, and the overall specific heat capacity of the stack is assumed to be a constant.

3.3 Wind Turbine

Wind turbines are used to convert the wind power into electric power. Electric generator inside the turbine converts the mechanical power into the electric power. Wind turbine systems are available ranging from 50W to 2-3 MW. The energy production by wind turbines depends on the wind velocity acting on the turbine. Wind power is used to feed both energy production and consumption demand, and transmission lines in the rural areas.

Wind turbines can be classified with respect to the physical features (dimensions, axes, number of blade), generated power and so on. For example, wind turbines with respect to axis structure: horizontal rotor plane located turbines, turbines with vertical or horizontal spinning directions with respect to the wind. Turbines with blade numbers: 3-blade, 2-blade and 1- blade turbines.

On the other hand, power production capacity based classification has four subclasses [7].

- Small Power Systems
- Moderate Power Systems
- Big Power Systems
- Megawatt Turbines

3.4 Buck – Boost Topology

Buck-boost dc/dc converter is used as depicted in Fig. 4. The parameters L and C in the buck-boost converter must satisfy the following conditions [11]

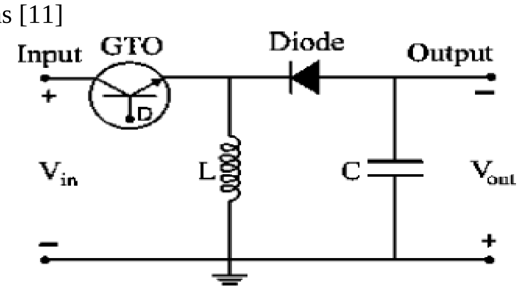


Figure – 4: Buck-boost topology

The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is a switched-mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the PWM generator. The basic principle of the buck–boost converter is fairly simple, The switch is turned-on, the input voltage source supplies current to the inductor, and the capacitor supplies current to the resistor (output load). When the switch is opened the inductor supplies current to the load via the diode. While in the on-state, the input voltage source is directly connected to the inductor (L). This results in accumulating energy in L. In this stage, the capacitor supplies energy to the output load. While in the off-state, the inductor is connected to the output load and capacitor, so energy is transferred from L to C and R.

IV. MULTILEVEL INVERTERS

Multilevel voltage source converters have been studied intensively for high-power applications. These converters synthesize higher output voltage levels with a better harmonic spectrum and less insulation stress. However, the reliability and efficiency of the converter are reduced due to an increasing number of devices. Today there is a large variety of converter topologies for medium voltage application. For medium power industrial applications (e.g. S = 300kVA - 30MVA) the majority of the industrial manufacturers offer different topologies of Voltage Source

Converters: Two-Level Voltage Source Converters (2L-VSC), Three-Level Diode clamped Voltage Source Converters (3L-DC VSC), Four- Level Flying Capacitor Voltage Source Converters (4L-FC VSC) and Series Connected H-Bridge Voltage Source Converters (SCHB VSC). While 4.5kV, 6kV and 6.5kV IGCTs are mainly used in DC VSCs and CSIs respectively; 2.5kV, 3.3kV, 4.5kV and 6.5kV High Voltage IGBTs (HVIGBTs) are applied in 2L-VSCs, 3L-DC VSCs and 4L-FLC VSCs [8].

4.1 Diode Clamped Multilevel Inverter

The most commonly used multilevel topology is the diode clamped inverter, in which the diode is used as the clamping device to clamp the dc bus voltage so as to achieve steps in the output voltage. Figure 5 shows the circuit for a diode clamped inverter for a three-level and a four-level inverter. The key difference between the two-level inverter and the three-level inverter are the diodes D_{1a} and D_{2a}. These two devices clamp the switch voltage to half the level of the dc-bus voltage. In general the voltage across each capacitor for an N level diode clamped inverter at steady state is $V_{dc}/n-1$. Although each active switching device is only required to block $V_{dc}/n-1$, the clamping devices have different ratings. The diode-clamped inverter provides multiple voltage levels through connection of the phases to a series of capacitors. According to the original invention, the concept can be extended to any number of levels by increasing the number of capacitors. Early descriptions of this topology were limited to three-levels where two capacitors are connected across the dc bus resulting in one additional level. The additional level was the neutral point of the dc bus, so the terminology neutral point clamped (NPC) inverter was introduced. However, with an even number of voltage levels, the neutral point is not accessible, and the term multiple point clamped (MPC) is sometimes applied. Due to capacitor voltage balancing issues, the diode-clamped inverter implementation has been limited to the three level. Because of industrial developments over the past several years, the three level inverter is now used extensively in industry applications. Although most applications are medium-voltage, a three-level inverter for 480V is on the market.

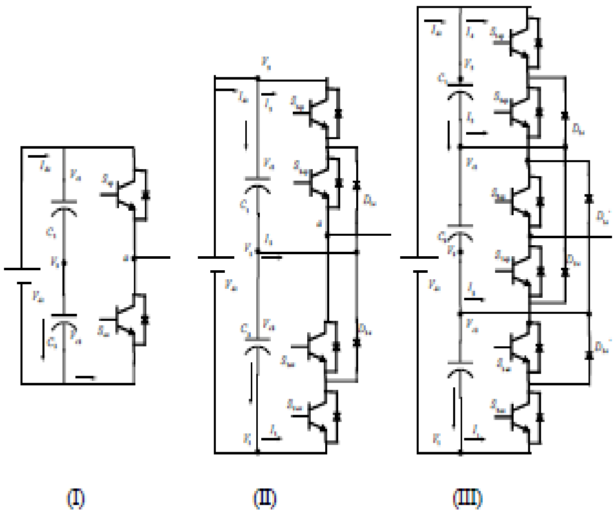


Figure – 5: Topology of the diode-clamped inverter (I) two-level inverter, (II) three-level inverter, (III) four-level inverter.

V. MULTILEVEL INVERTER CONTROL STRATEGIES

5.1 Seven Level Diode-Clamped Inverter

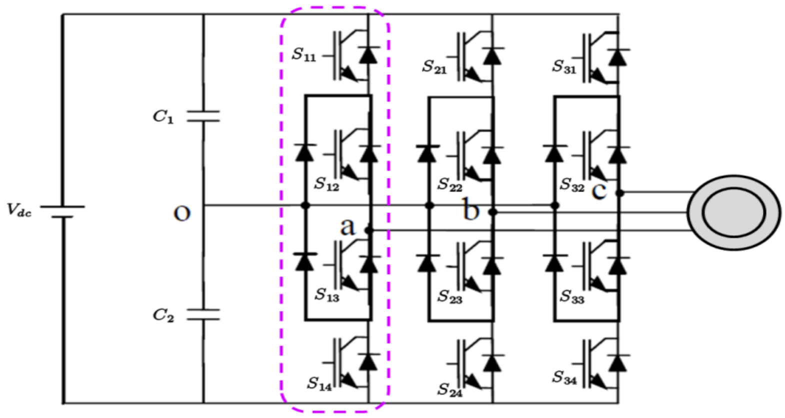
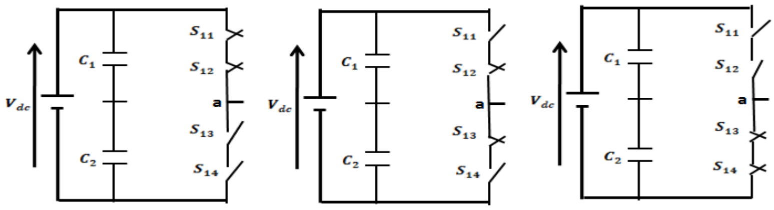


Figure – 6: Seven level diode clamped inverter



a. Sequence 1 b. Sequence 2 c. Sequence 3

Figure - 7: Different possible configurations for one arm

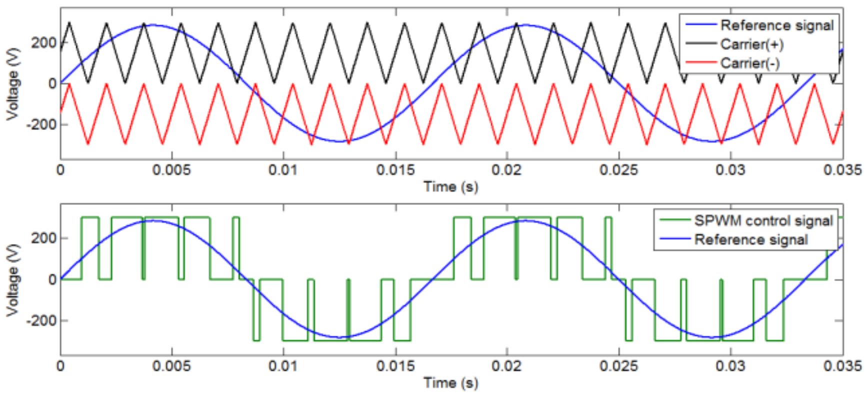


Figure - 8: Seven level SPWM control method

TABLE 1: Sequences of control vectors

S	**[S_{11}, S_{12}, S_{13}, S_{14}]**	**V_{ao}**
1	[1 1 0 0]	V_{ao}
2	[0 1 1 0]	0
3	[0 0 1 1]	V_{ao}

the same as the reference voltage Vra frequency.
The inverter output voltages are written as follow (1):

$$\begin{cases} V_{ao} = \frac{1}{3}(V_{ab} - V_{ca}) \\ V_{bo} = \frac{1}{3}(V_{bc} - V_{ab}) \\ V_{co} = \frac{1}{3}(V_{ca} - V_{bc}) \end{cases} \quad (1)$$

5.2 Nine Level Diode-Clamped Inverter

To increase the power quality of the renewable sources nine level diode clamped inverter is used in the simulation and the comparison is made between the seven level and nine level diode clamped inverter. The operation of nine level inverter is explained below.

The operations for each phase are performed by connecting 10-gate drives and using the DC voltage sources from the hybrid system to work with four capacitors per phase. The inverter employed the technique of proportional reduces harmonic elimination type to control switching equipment in the circuit to providing appropriated waveform and increasing the efficiency at high performance.

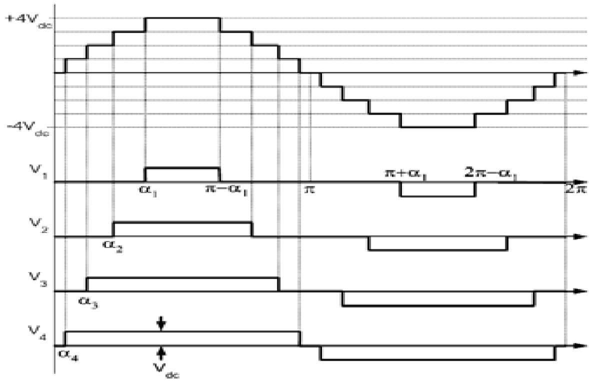


Figure - 9: Nine level SPWM control method

VI. SIMULINK CIRCUIT

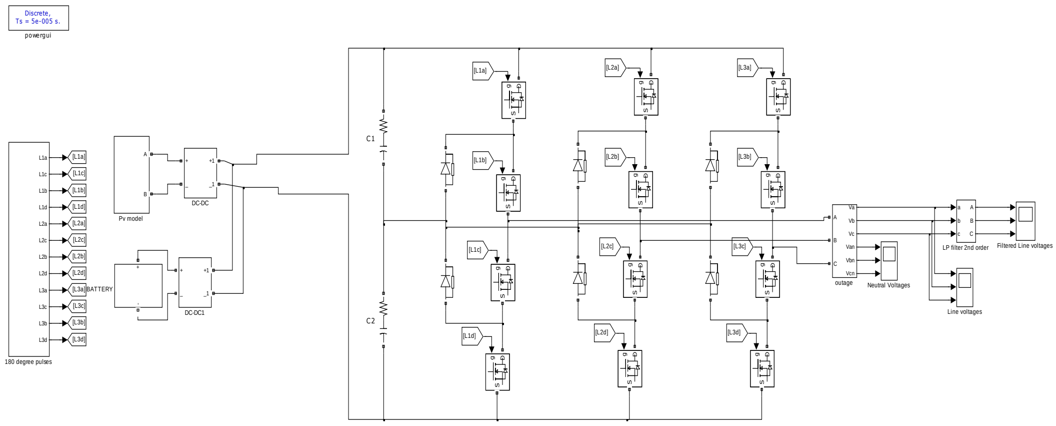


Figure - 10: Simulink Circuit of the seven level diode clamped inverter

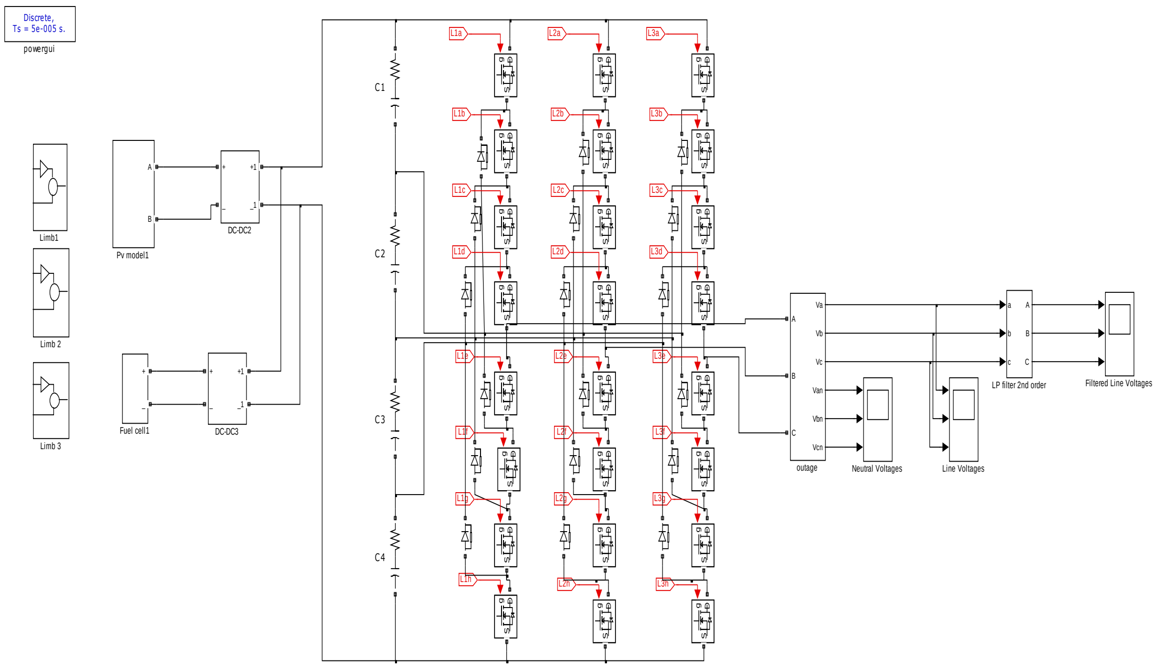


Figure - 11: Simulink Circuit of the nine level diode clamped inverter

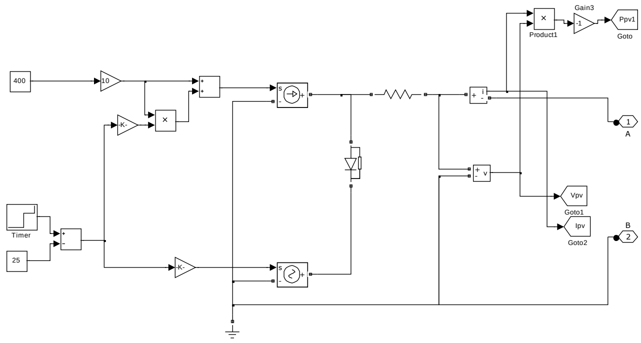


Figure - 12: Simulink Diagram of PV Array

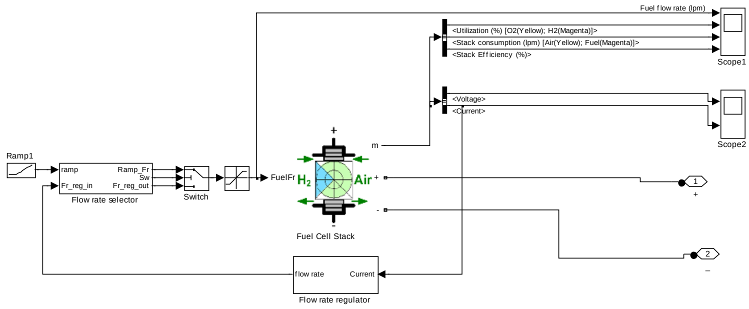


Figure - 13: Simulink Diagram of Fuel Cell

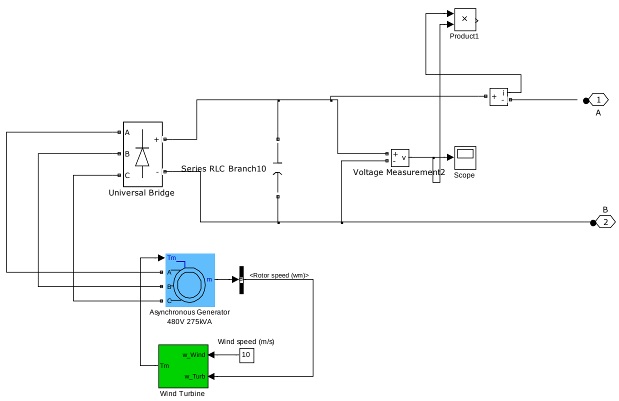


Figure – 14: Simulation model for wind mill

VII. SIMULATION RESULTS

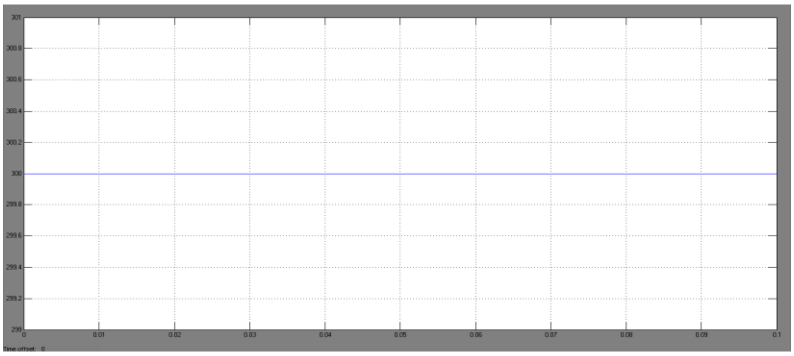


Figure - 15: Voltage from three RES (at DC bus bar)

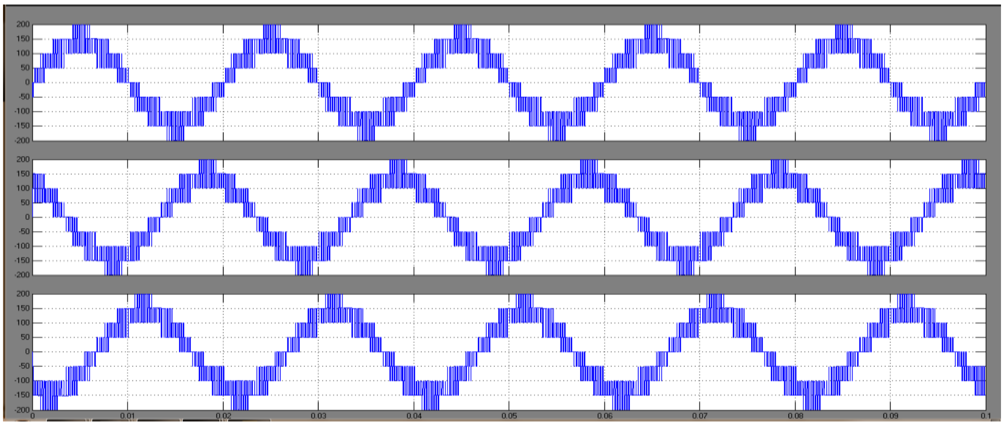


Figure - 16:seven level diode clamped inverter output Voltage without filter

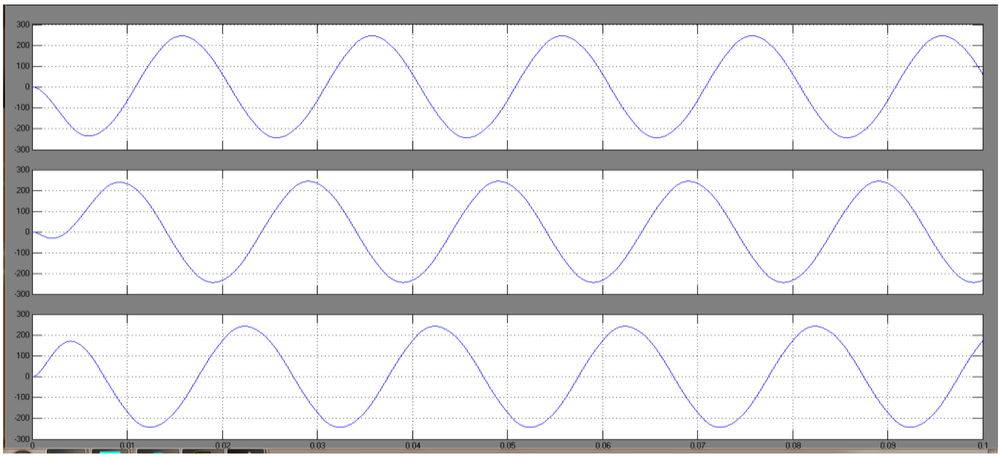


Figure - 17: Seven level diode clamped inverter output Voltage with filter

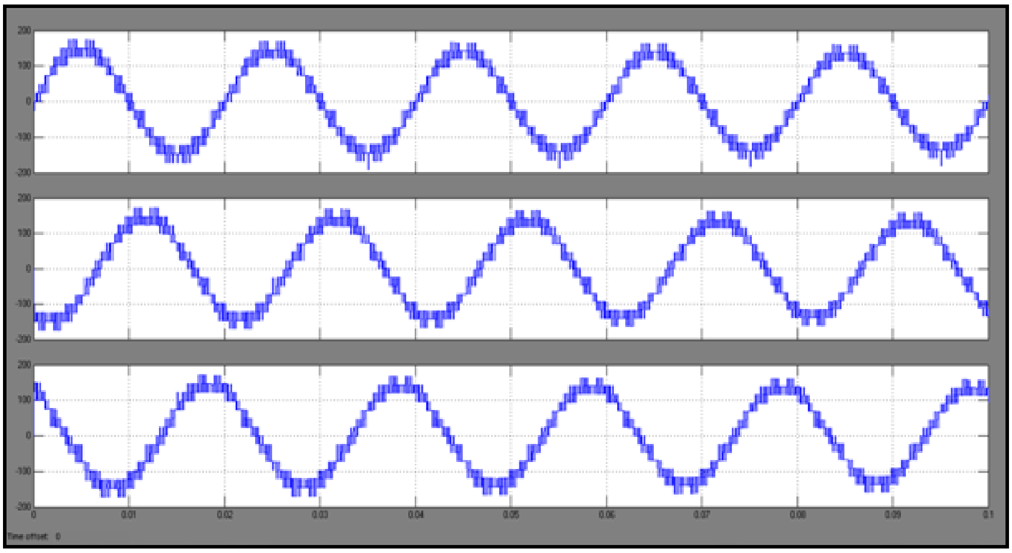


Figure - 18:Nine level diode clamped inverter output Voltage without filter

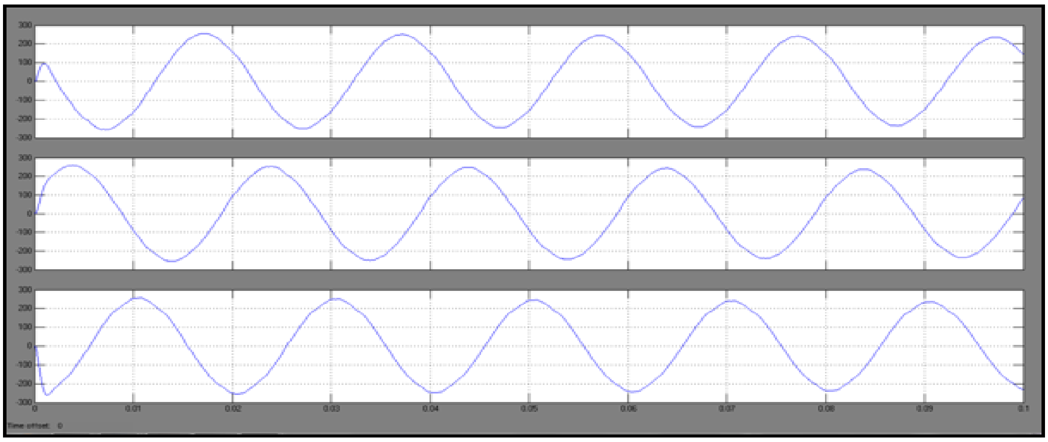


Figure - 19: Nine level diode clamped inverter output Voltage with filter

VIII. TOTAL HARMONIC DISTROTION ANALYSIS OF MULTILEVEL INVERTER

The main criterion for assessing the quality of the voltage delivered by an inverter is the Total Harmonic Distortion (THD). This section will be devoted to analysing the inverters performance according to their number level. Level three, seven inverters will be considered. The goal is to see if the low order harmonics amplitude will decrease when the number of level increases. The inverter is usually followed by a low pass filter since higher frequency harmonics are easy to filter. This means that the performance of multilevel inverters can be improved by cancelling or reducing lower order harmonics. Lower order harmonics generate the most important currents when an inductive load is used.

The THD is a ratio between the Root Mean Square (RMS) of the harmonics and the fundamental signal. For an inverter that has a fundamental output voltage V1 and harmonics V2, V3,. . . , we define the THD as follows:

$$THD = \frac{\sqrt{\sum_{k\geq 2}^{N} V_k^2}}{V_1} \qquad (10)$$

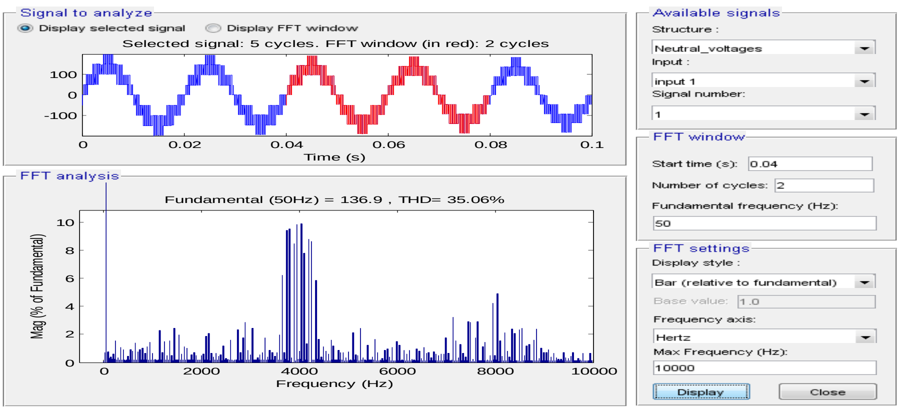


Figure - 20: FFT Analysis of the seven level diode clamped Inverter Voltage (35.06%)

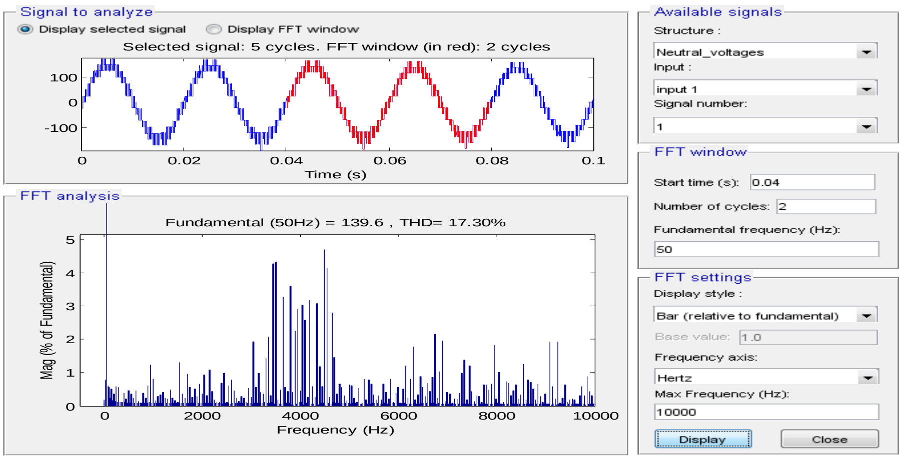


Figure - 21: FFT Analysis of the nine level diode clamped Inverter Voltage (17.30%)

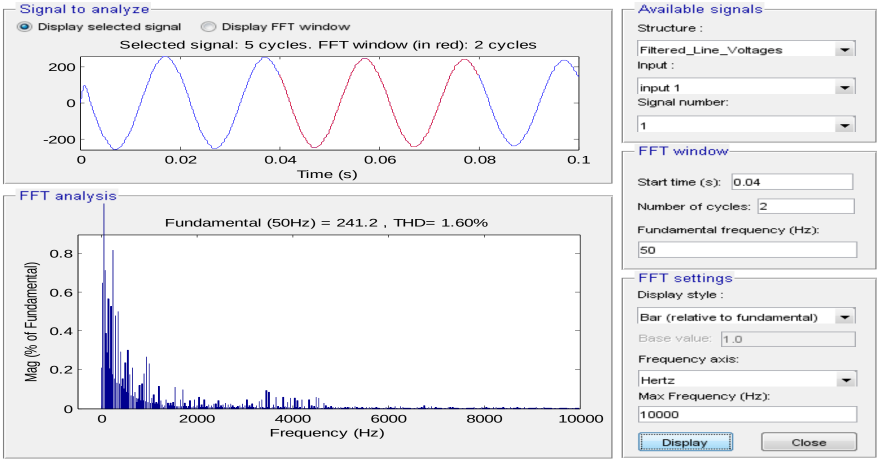


Figure - 22: FFT Analysis of the nine level diode clamped Inverter Voltage with filter (1.60%)

IX. Conclusion

In this paper, a general multilevel SPWM control algorithm for *n-level* inverter has been modelled and simulated using Matlab®/Simulink. This algorithm can generate automatically SPWM pulses for any level of inverter by changing only a parameter *n* which is the number of inverter level. Simulation of 7 and 9 level inverter connected to load has been performed and the generated signals THD is analysed. The system is supplied by a PV panel and batteries bank and wind mill. That gives energy autonomy to the system. Simulation results give a better quality of stator current in terms of low harmonics, thus reducing the adverse effects on of the machine life and eventually the electrical network which supplies it. These latter can be easily eliminated with a simple low-pass filter. So it is not necessary to continue increasing the inverter level.

References

[1] R. Teodorescu , F. Beaabjerg , "*Multilevel converters - A survey*", Proc. EPE'99, pp. 1999.

[2] Z. Yan, M. Jia, "*An Integration SPWM Strategy for High- Frequency Link Matrix Converter With Adaptive Commutation in One Step Based on De-Re-Coupling Idea* ", Industrial Electronics, IEEE Transactions on, Vol. 59 , pp. 116-128, 2012.

[3] Wu, F.J., "*Single-phase three-level SPWM scheme suitable for implementation with DSP*", Electronics Letters, Vol. 47, pp. 994- 996, 2011

[4] D.G. Holmes, and P.M. Brendan, "*Opportunities for harmonic cancellation with carrier based PWM for two level and multilevel cascaded inverters*", IEEE Trans. on Industry Applications, Vol.37, No.2, pp. 574-582, 2001.

[5] L. Li, C. Dariusz, and Y. Liu, "*Multilevel space vector PWM technique based on phase-shift harmonic suppression*" Applied Power Electronics Conference and Exposition (APEC), Vol.1, pp. 535-541, 2000.

[6] L. M. Tolbert, "*Multilevel Converters for Large Electric Drives*", IEEE Trans. on Ind. Application, Vol. 35, pp. 36-44, 1999.

[7] L. Tian, S. Qiang, L. Wenhua, C. Yuanhua, and L. Jianguo, "*FPGAbased universal multilevel space vector modulator*" in Proc. IECON 32nd Annu. Conf., pp. 745–749, 2005.

[8] D. Ning-Yi, W. Man-Chung, and H. Ying-Duo, "*Application of a three level NPC inverter as a three-phase four-wire power 22 quality compensator by generalized 3DSVM*" IEEE Trans. Power Electron., vol. 21, no. 2, pp. 440–449, Mar. 2006.

[9] M. A. Tankari, M.B.Camara, B. Dakyo, C. Nichita, "*Ultracapacitors and Batteries control for Power Fluctuations mitigation in Wind-PV-Diesel Hybrid System*", Int. Conf. EVER'11, Monte-Carlo, Mars 2011.

[10] M. A. Tankari, M.B.Camara, B. Dakyo, "*DC-bus Voltage Control in Multi-sources System – Battery and Supercapacitors*", the 37th Annual Conf. of the IEEE Industrial Electronics Society IECON, Melbourne - Australia, Nov. 2011.

[11]. Dr. L. Venkata Narasimha Rao, G.G. Raja Sekhar, T. Vijay Muni, "*Analysis of Total Harmonic Distortion for PV – Battery Hybrid System with Multilevel Inverter*" International Journal of Latest Research in Engineering and Computing (IJLREC), volume 1, issue 1: Page No 96-103, September – October 2013.